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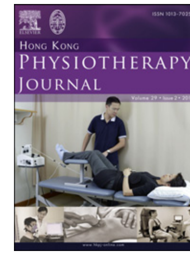

RESEARCH REPORT

Effectiveness of electromyographic biofeedback training on quadriceps muscle strength in osteoarthritis of knee[†]

Shahnawaz Anwer, MPTh (Orthopaedics) [a,*], Nishat Quddus, MPTh (Osteomyology) [b], Mohammad Miraj, MPTh (Osteomyology), MBA, PGDM, PGDCR [c], Ameed Equebal, MD (PMR) [d]

[a] *Indoor Physiotherapy Department, National Institute for the Orthopedically Handicapped, B.T. Road, Bonhoogly, Kolkata, India*
[b] *Faculty of Allied Health Sciences, Jamia Hamdard University, New Delhi, India*
[c] *Department of Physiotherapy, Institute of Health and Management Studies, New Delhi, India*
[d] *Department of Rehabilitation, National Institute for the Orthopedically Handicapped, B.T. Road, Bonhoogly, Kolkata, India*

KEYWORDS
arthritis;
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strength

Abstract The objective of this randomised controlled trial was to evaluate the effectiveness of electromyographic biofeedback as an add-on therapy with isometric exercise on quadriceps strengthening in patients with osteoarthritis of knee. Thirty three, 10 men and 23 women, patients with osteoarthritis of knee participated in the study. Patients were randomly placed into two groups: a biofeedback group ($n = 17$) and a control group ($n = 16$). The biofeedback group received electromyographic biofeedback-guided isometric exercise programme for 5 days a week for 5 weeks, whereas the control group received an exercise programme only. On between-group comparisons, the maximum isometric quadriceps strength in biofeedback group, at the end of 5th week was significantly greater than that of the control group ($p < 0.004$). The addition of electromyographic biofeedback to a 5-week isometric exercise program appeared to increase quadriceps muscle strength, compared to the exercise program alone for people with knee osteoarthritis. The finding, however, should be interpreted with caution due to limitations of the study design.

* Corresponding author. Indoor Physiotherapy Department, National Institute for the Orthopedically Handicapped, B.T. Road, Bonhoogly, Kolkata 700090, India.
E-mail address: anwer_shahnawazphysio@rediffmail.com (S. Anwer).

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Introduction

Osteoarthritis (OA) is a frequent and prevailing musculoskeletal disorder affecting a wide range of population throughout the world. It is estimated that 80% of all adults aged 65 years or older exhibit radiographic evidence of OA [1,2]. A recent World Health Organization report on the global burden of the disease indicates that knee OA is likely to become the fourth most important global cause of disability in women and the eighth most important in men [3]. A recent survey in India established OA in older age greater than 65 years to have a prevalence of 32.6% in rural and 60.3% in urban population [4].

OA causes joint pain, typically worse with weight bearing and activity, and stiffness after inactivity [5]. Susceptibility to OA may be increased in part by genetic inheritance (a positive family history increases risk), age, ethnicity, diet, and female gender. In persons vulnerable to the development of knee OA, local mechanical factors, such as abnormal joint congruity, malalignment (varus or valgus deformity), muscle weakness, or alterations in the structural integrity of the joint environment (such as meniscal damage or ligament rupture), facilitate the progression of OA. Loading can also be affected by obesity and joint injury (either acutely as in a sporting injury or after repetitive overuse, such as occupational exposure), both of which can increase the likelihood of development or progression of OA [6].

Lower extremity muscle weakness may play an important role in knee OA. It has been well established in cross-sectional studies that individuals with symptomatic knee OA have weaker quadriceps than the age-matched individuals without knee OA [7,8]. The weakness associated with knee OA is largely thought to be the result of disuse atrophy secondary to joint pain. Results of other studies suggest that quadriceps weakness increases the risk of disability in persons with knee OA [7].

Recommendations for management of OA focus on a combination of pharmacological and nonpharmacological treatments. Most of the nonpharmacological treatments have been studied in patients with hip and knee OA with a special focus on exercise, physical activity, patient education, and weight control. Reduced pain and improved function have been documented in patients with knee OA, and exercises and information are considered as important nonpharmacological interventions for this patient group [9]. Treatment guidelines for OA of the knee have considered exercise as an important nonpharmacological approach [10]. A growing body of evidence shows that exercise improves knee joint function and decreases symptoms [11–13].

Many authors recommend therapeutic exercises, especially the isometric exercises and short arc knee extension exercise at the terminal range for chronic OA knees [14]. A possible advantage of isometric training may be that it does not stress the joint over a functional range of motion. Reduced joint movement may result in less pain during and after the resistance training [5,15].

The use of electromyographic (EMG) biofeedback as an adjunct therapy to standard exercise regime for increasing muscle strength has been investigated in several studies. Adamovich et al [16] studied the effects of EMG biofeedback on static contraction of quadriceps muscles. The experimental group, which received auditory and visual EMG feedback while exercising, demonstrated significantly greater strength gains than the control group, which received no form of feedback. Similarly, Lucca and Recchiuti [17], Waly et al [18], and Khalil et al [19] found that isometric exercise coupled with EMG biofeedback led to significantly greater gains in strength than did isometric exercise alone.

Croce [20] investigated the effect of EMG biofeedback application on quadriceps muscle strengthening in healthy volunteers, and the EMG values of muscle activity and quadriceps muscle strengthening in the EMG biofeedback group were found to be significantly greater than those in the placebo and nonbiofeedback groups. Till date, no study has examined the effectiveness of EMG biofeedback training in patients with OA of knee. Hence, the present study was intended to evaluate the effectiveness of EMG biofeedback as an add-on therapy with standard exercise for quadriceps strengthening in patients with OA of knee.

Materials and methods

Study design

A randomised controlled trial design was selected for testing the hypothesis, where a baseline reading was taken before the intervention, and posttest reading was taken at the end of 2nd week, 3rd week, and 5th week. These readings were then compared to find out the effect on the dependent variable. The outcome measure or dependent variable selected for this study was isometric quadriceps strength. The quadriceps strength was measured using electronic strain gauge device (Fig. 1). It is a reliable and valid tool to measure muscle strength [21]. Kennedy et al [21] reported that test-retest correlation ranged from 0.81 to 0.94. They discussed whether strain gauge measurement was correlated with the other measurement and found that it was highly correlated with that of cable tensiometer and maximal load lifted. This can be considered a form of criterion-related validity, that is, does one type of measurement have the ability to predict another? Some studies stated that the instrument has a sound theoretical basis to reflect muscle tension, which is a form of construct validity [22].

Patients

A total of 43 patients were assessed for eligibility. Ten patients did not satisfy the inclusion criteria, and three dropped out because of medical problem. Hence, a total of 30 (nine men and 21 women) patients with OA of knee completed the trial. The criteria for inclusion were as follows: radiological evidence of primary OA with Grade 2 on the Kellgren-Lawrence Scale; age between 40 years and 65 years; unilateral or bilateral involvement—in case of bilateral involvement more symptomatic knee was included; and pain in and around knee. The patients were excluded if they had any deformity of knee (fixed flexion deformity), hip, or back; any central or peripheral nervous

Figure 1. Electronic strain gauge instrument.

system involvement; received steroids or intra-articular injection within previous 3 months; had systemic inflammatory disease, for example, gout, rheumatoid arthritis; were uncooperative; and received physiotherapy treatment in the past 6 months. This study was approved by the ethical committee of Jamia Hamdard University, New Delhi, India.

Procedure

The patients were screened first according to the inclusion and exclusion criteria (Fig. 2). They were randomised by computer-generated number into experimental and control groups—biofeedback group consisting of 17 patients and control group consisting of 16 patients. It was a single-blind study, that is, the evaluator, but not the participants, knew the group assignment. Two patients in the biofeedback group and one patient in control group did not receive intervention because of some medical problems. Fifteen patients in each group completed the trial. An informed consent was obtained from the patients.

Group A (experimental group): EMG biofeedback—guided isometric exercise and moist heat.
Group B (control group): sham EMG biofeedback along with isometric exercise and moist heat.

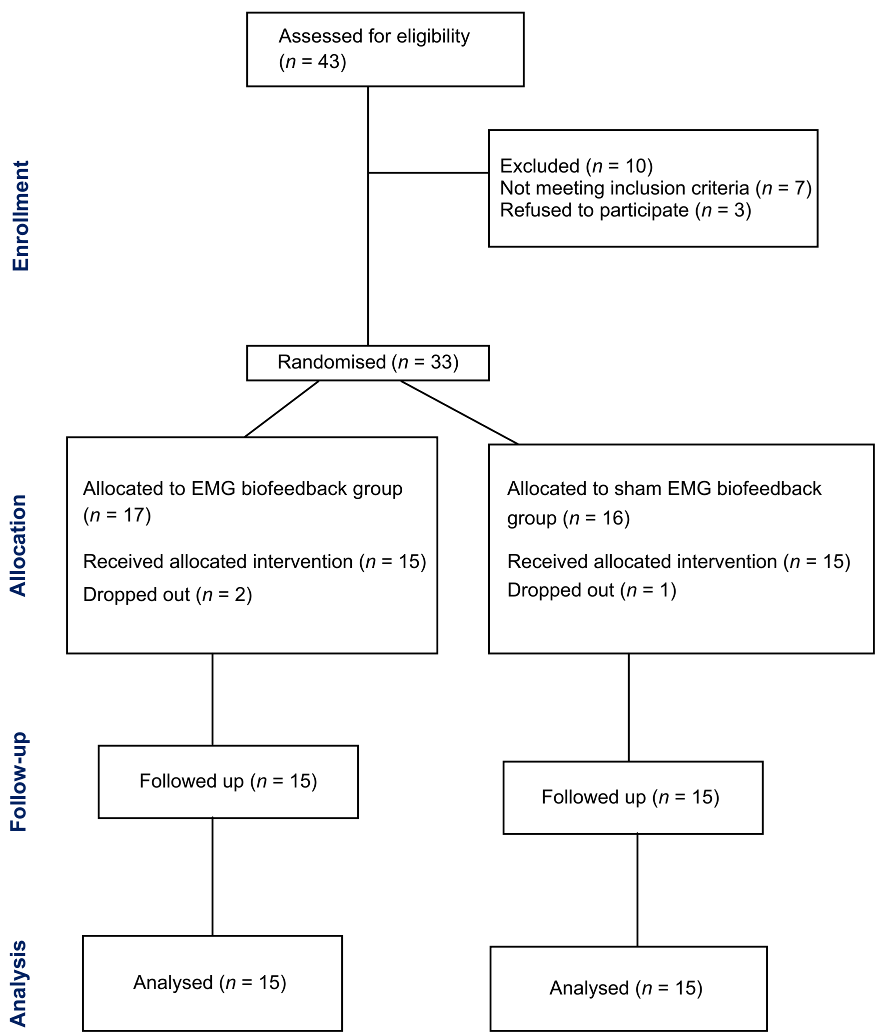

Figure 2. CONsolidated Standards of Reporting trials (CONSORT) diagram showing the flow of participants through each stage of a randomised trial. EMG = electromyographic.

Measurement of isometric strength

The isometric strength of quadriceps femoris was measured at baseline (before the treatment) and at the end of 2nd week, 3rd week, and 5th week. During the testing, the patients were made to sit on the quadriceps table with the knee joint in 60° of flexion. Sixty degrees of knee flexion was used because this position has been found to result in the greatest torque output [23]. The thigh was stabilised with a belt; the shin pad of the lever arm was positioned proximal to the ankle. The fulcrum of the lever arm was aligned with the most inferior aspect of the lateral epicondyle of the femur. A strain gauge was attached to the distal end of the quadriceps table arm. Each test included three consecutive 5-second trials with 30-second rest between trials. The mean of the readings was used for the purpose of analysis.

Figure 3. Electromyographic biofeedback instrument (Myomed 932; Enraf Nonius).

Intervention

The experimental group received the EMG biofeedback—guided isometric exercise programme. The other group received the isometric exercise programme along with sham EMG biofeedback. Both the groups received moist heat by hydrocollator pack for 20 minutes before exercise. Moist heat was given before the exercise session with the patient in supine position. The patient was asked to expose the area to be treated. Hydrocollator pack was wrapped under towel and applied over the knee for 20 minutes. It was given for 3 weeks (5 d/wk).

Biofeedback training

Biofeedback training was performed with a Myomed 932 (Enraf Nonius, Rotterdam, The Netherlands), a two-channel EMG machine (Fig. 3). Clear and full screen displayed the EMG signal with a curve obtained for both vastus medialis oblique (VMO) and rectus femoris (RF).

Electrode placement

Before the electrode placement, the patients were asked to shave the part, and then, the part to be treated was thoroughly washed by alcohol solutions to clean the area and to reduce skin resistance. Skin adhesive surface electrodes were used to record muscle activity. Two electrodes were placed 4 cm superior and 3 cm medial to superomedial border of patella to record the recruitment of VMO. Other electrodes were placed at the junction of the middle and lower third of the thigh, slightly medially and angled downward and medially (i.e. midway between a line drawn between the base of patella and the anterior superior iliac spine) for RF. The two active electrodes from each channel were placed as close together as possible along the directions of the fibres of each muscle. The reference electrode was placed below the tibial tubercle (Fig. 4).

Exercise procedure

Group A

Four sets of exercise were given for 5 weeks, for 5 days a week. The patients were explained about the procedure and asked to watch the muscle activity and try to increase the activity level of VMO and RF while performing the exercises. After each 5-second hold, the patient was asked to take rest for 10 seconds. The training sessions were held 5 days a week for 5 weeks. Before each session, the patient was asked to contract the quadriceps muscle maximally three times while the activity level of the VMO and RF was monitored by EMG biofeedback device. The average of these three maximum contractions was lowered by 20% for each muscle to determine their threshold levels. During the training session, the patients were instructed to contract the VMO and RF above its threshold level and to maintain the audible signal for 5 seconds.

Isometric quadriceps exercise. Patients were positioned in supine lying. A roll of towel was put beneath the knee. They were instructed to maximally activate their thigh muscles above their threshold level to straighten their knees and maintain the audible signal for 5 seconds. This exercise had three sets of 10 repetitions each.

Terminal knee extension exercise. The knee extension exercise was performed with the patient in a sitting position with the knee flexed from 30° to 0°. Patients were instructed to maximally activate their thigh muscles above their threshold level to straighten their knees and to

Figure 4. Electrode placements for vastus medialis oblique and rectus femoris during electromyographic biofeedback training.

Table 1 Details of patients

Group	No. of patients	Gender		Age	Weight	Height	BMI
		Male	Female				
A	15	4	11	54.40 ± 7.73	64.93 ± 5.61	155.26 ± 4.41	26.93 ± 2.08
B	15	5	10	55.27 ± 7.08	65.86 ± 4.34	155.20 ± 3.40	27.34 ± 1.35

Data are presented as mean ± standard deviation.
BMI = body mass index.

maintain the audible signal for 5 seconds. This exercise had three sets of 10 repetitions each.

Straight leg raising exercise. Patients were positioned in supine lying. They were instructed to perform a maximum isometric quadriceps contraction before the lifting phase of exercise. Then, the patients were instructed to lift the leg and to maintain the audible signal for 5 seconds. This exercise had three sets of 10 repetitions each.

Isometric hip adduction exercise. Patients were positioned in supine lying. A small pillow was put between the knees. They were instructed to perform isometric hip adduction exercise by pressing the pillow between the knees and to maintain the adduction contraction above its threshold level during the audible signal for 5 seconds. This exercise had three sets of 10 repetitions each.

Group B

The same set of exercises was given to Group B also, but the electrodes were placed away from the VMO and RF, and the reference electrode was placed below the tibial tuberosity. Biofeedback unit was turned on for control group as well. Here, the patients were doing exercises without any instruction to increase the recruitment of VMO and RF muscle.

Statistical analysis

Statistical analysis was done using SPSS 15.0 software (SPSS Inc., Chicago, IL, USA). An independent *t* test was used to compare the differences in isometric quadriceps strength between the two groups at baseline and at the end of 2nd week, 3rd week, and 5th week. Repeated measures of analysis of variance followed by *post hoc* *t*-tests with Bonferroni adjustment were used to study the changes in isometric quadriceps strength in each group at the end of 2nd week, 3rd week, and 5th week. The level of statistical significance was set at $p < 0.05$. First, we performed an intention-to-treat analysis; after that, we performed an "on-protocol analysis" by removing the dropouts and only analysing the data of the 30 patients. After analysing these results, we found that the intention-to-treat analysis yields similar results as the on-protocol analysis.

Results

The demographic details, including age, weight, height, and body mass index, were recorded. Table 1 gives the details of the mean and standard deviation of these scores. These variables had no significant difference between the two groups.

The baseline reading of quadriceps strength for both the groups was not statistically significant ($p = 0.60$) (Fig. 5). On comparing the strength at 2nd week between the two groups, an insignificant difference was obtained at $p = 0.23$ (CI, 0.53–2.32). The reading of strength at 3rd week was found to be statistically significant between the groups at $p = 0.011$ (CI, 0.85–3.55). The measurement of quadriceps strength at the end of 5th week showed statistically significant improvement in EMG biofeedback group compared with the control group at $p = 0.000$ (CI, 1.28–3.95) (Table 2). The mean (standard deviation) improvement of quadriceps strength in Group A was found to be 4.61 (0.12), and in Group B, it was found to be 1.64 (0.30).

On comparing the values between baseline and after 2nd week, a significant improvement was noted in both groups ($p < 0.05$). The mean improvement in Group A was 2.86 ± 0.21 and that in Group B was 1.63 ± 0.06. Comparison of strengths between 2nd week and 3rd week revealed significant improvement in Group A ($p < 0.05$) whereas an insignificant improvement in Group B ($p > 0.05$). The mean improvement in Group A was 1.40 ± 0.10 and that calculated in Group B was 0.49 ± 0.10. Comparison of strengths between 3rd week and 5th week revealed an insignificant improvement in both groups ($p > 0.05$) (Tables 3 and 4).

The results obtained on comparison of the readings at Day 1 and at 3rd week showed a significant improvement in both groups ($p < 0.05$). The mean improvement in Group A was found to be 4.26 ± 0.19, and in Group B, it was found to be 2.12 ± 0.30. The results obtained on comparison of readings at Day 1 and 5th week showed a significant improvement in both the groups ($p < 0.05$). The mean improvement in Group A was found to be 4.61 ± 0.12, and in group B, it was found to be 1.64 ± 0.30 (Tables 3 and 4).

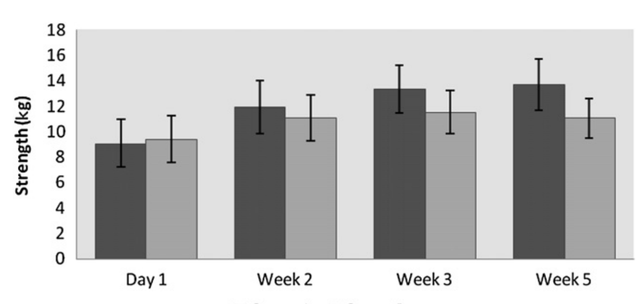

Figure 5. Comparison of isometric quadriceps strengths between the groups by mean (standard deviation).

Table 2 Comparison of isometric quadriceps strength between the groups

Variables	Group A ($n = 15$)	Group B ($n = 15$)	Independent t test		95% Confidence interval of the difference	
			t	p	Lower	Upper
STN_0	9.07 ± 1.87	9.42 (1.86)	0.518	0.608	1.75	1.04
STN_2	11.93 ± 2.08	11.05 (1.80)	1.228	0.230	0.53	2.32
STN_3	13.33 ± 1.89	11.54 (1.70)	2.723	0.011	0.85	3.55
STN_5	13.68 ± 1.99	11.06 (1.56)	4.007	0.000	1.28	3.95

Data are presented as mean $\pm$ standard deviation.
STN_0 = baseline reading of strength at Day 1; STN_2 = reading of strength at Week 2; STN_3 = reading of strength at Week 3; STN_5 = reading of strength at Week 5.

Discussion

The purpose of the study was to assess the effectiveness of EMG biofeedback as an adjunct to strength training of quadriceps muscle to increase the strength of the quadriceps muscle in patients with OA of knee. A randomised controlled trial design was selected for testing the hypothesis. It was a single-blind study, that is, the evaluator knew the group assignment but the participants were unknown of it. The data showed that 5 weeks of training period brought significant improvement in both EMG biofeedback and control groups at 2nd week, 3rd week, and 5th week. However, the results of the study demonstrated that a combination of EMG biofeedback and isometric exercises brought greater gains in isometric quadriceps strength. The effects were largely gained during the 5 weeks of treatment period.

The posttest intergroup comparison showed significant improvement in the EMG biofeedback group at the end of 5th week. In between-group analysis, the improvement of strength in EMG biofeedback group was 23% greater than that of control group at the end of the training period. Differences in strength gains by EMG biofeedback group may be explained by the study carried out by Basmajian [24] who has demonstrated that, with the help of auditory and visual cues, patients could control the recruitment and the frequency of discharge of motor units. In terms of the present study, one might hypothesise that the visual and auditory cues from the biofeedback unit enabled Group A to consciously increase either the frequency of discharge of the active motor neurons or the number of motor units recruited. Therefore, one could further hypothesise from the work of Basmajian [24] that, because of more fibres firing and a possibly faster rate, Group A produced a greater amount of tension during the testing and training sessions.

Furthermore, Moritani and DeVries [25] described neural factors as a facilitation occurring as a result of neurological reorganisation. Although not yet clearly understood, this theory hypothesises that the persistent recruitment increases the numbers of motor units by means of biofeedback, causing a reorganisation of facilitation patterns. This reorganisation may be responsible for either the increased firing rate or the increased number of motor units recruited, as demonstrated by greater gains in strength in Group A that was exposed to biofeedback.

The study result can also be explained on the basis of the findings of Waly et al [18] and Khalil et al [19]. They investigated the physiological basis underlying the increase in muscle strength associated with the use of feedback and found that muscle strength increase could be attributed to (1) an increase in the average firing rate; (2) an increase in the motor unit recruitment; and (3) occurrence of synchronisation of the active motor unit. As such, the increases in strength associated with feedback appear to be the result of changes in both motor unit firing rate and recruitment patterns.

Adamovich et al [16] studied the effect of EMG biofeedback on static contraction of quadriceps muscle. All patients performed exercise on a Cybex Isokinetic Machine. The experimental group, which received auditory and visual EMG feedback while exercising, demonstrated significantly greater strength gains than the control group.

Similarly, Lucca and Recchiuti et al [17] and Khalil et al [19] found that greater gains in strength were achieved with EMG biofeedback than with exercise alone. Another study carried out by Croce [20] showed that a training programme that uses EMG biofeedback with

Table 3 Comparison of isometric quadriceps strengths within the groups

Group	STN_0 ($n = 15$)	STN_2 ($n = 15$)	STN_3 ($n = 15$)	STN_5 ($n = 15$)	Repeated ANOVA	
					F	p
A	9.07 ± 1.87	11.93 ± 2.08	13.33 ± 1.89	13.68 ± 1.99	112.09	0.000
B	9.42 ± 1.86	11.05 ± 1.80	11.54 ± 1.70	11.06 ± 1.56	46.32	0.000

Data are presented as mean $\pm$ standard deviation.
ANOVA = analysis of variance; STN_0 = baseline reading of strength at Day 1; STN_2 = reading of strength at Week 2; STN_3 = reading of strength at Week 3; STN_5 = reading of strength at Week 5.

Table 4 Pairwise comparison of isometric quadriceps strengths within the groups using "*p*" values

Group	*Post hoc* analysis (Bonferroni test)					
	STN_0-STN_2	STN_0-STN_3	STN_0-STN_5	STN_2-STN_3	STN_2-STN_5	STN_3-STN_5
A	0.000	0.000	0.000	0.000	0.000	0.896
B	0.000	0.000	0.000	0.100	1.000	0.176

STN_0 = baseline reading of strength at Day 1; STN_2 = reading of strength at Week 2; STN_3 = reading of strength at Week 3; STN_5 = reading of strength at Week 5.

isokinetic exercise produces significant gains in maximal strength of leg extensor muscles. Middaugh et al [26] evaluated the effectiveness of EMG biofeedback in improving voluntary control over the abductor hallucis muscle; they compared voluntary control with and without biofeedback under controlled experimental conditions. They found that the EMG biofeedback condition was associated with better improvement in voluntary control over abductor function.

However, in contrast to the aforementioned studies, the recent study carried out by Yelmaz et al [27] found no superiority of EMG biofeedback—assisted strengthening-exercise programme to strengthening-exercise programme without EMG biofeedback. The differences in their results may be because of different treatment protocols, measurements, and patient characteristics. In strengthening-exercise programme, they included quadriceps isometrics, closed kinetic chain (mini squatting), and hip adductor isometric and progressive resistive exercises, compared with our study where we included only isometric types of exercises. In their study, all patients were taken into a supervised-group strengthening-exercise programme three times a week, for 3 weeks. The patients were also asked to perform the same exercise programme regularly twice a day at home at these days. However, the authors did not explain how they controlled the adherence of home exercise programme in both groups. Furthermore, different measurement methods may contribute to the difference in the findings. They used isokinetic dynamometry for measuring quadriceps strength, which is a more valid and reliable tool compared with the strength gauge device. The major difference was found in the patient characteristics. In their study, around 90% of the patients were females compared with 70% females in our study. Moreover, they include the patient on the basis of American Criteria Rheumatology compared with our study where we include a patient on the basis of Kellgren-Lawrence Scale. They exclude only those patients having Grade 4 OA of knee as per Kellgren-Lawrence, whereas we include only those with Grade 2 OA of knee as per Kellgren-Lawrence Scale, which seems to be less severe. Hence, all these factors may contribute to the difference in findings. Thus, significant differences in improvement of isometric quadriceps strength in biofeedback group in the present study can be justified on the basis of the aforementioned theories and past studies on strength training.

The major limitation of this study was the small sample size consisting of only 30 patients in the study. Moreover, the duration of study is not adequate to study the long-term effect of the EMG biofeedback. As the evaluator knows the group allocation, it may reduce the validity of the measurements and results. Double-blind study would have improved the reliability of the measurements and results. Inclusion of an isokinetic device could have given more reliable information on the muscle strength than that by a strain gauge device. Because of the lack of functional outcome, such as Western Ontario and McMaster Universities osteoarthritis index score, we cannot predict the effect of this training protocol on functional status. Further study is warranted in this area.

Implication for clinical practice

Although EMG biofeedback has been used in the treatment of a variety of medical disorders, such as stroke and headache, less attention has been paid to application in the area of musculoskeletal disorders. As suggested by the present study, ability to use this type of feedback during exercise makes it a particularly promising therapeutic approach for orthopaedic problems. Strength training with EMG biofeedback may be useful in decreasing the time for rehabilitation and maximising the recovery potential of patients of OA of knee with decreased quadriceps femoris muscle strength; it may permit earlier initiation of vigorous strength training if there are precautions to dynamic strengthening techniques.

Conclusion

The addition of EMG biofeedback to a 5-week isometric exercise programme appeared to increase quadriceps muscle strength compared with the exercise programme alone for people with knee OA. The finding, however, should be interpreted with caution because of limitations of the study design.

Acknowledgements

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